Photometry of Uranus' Rings: A Scientific Journey Through Space Fashion

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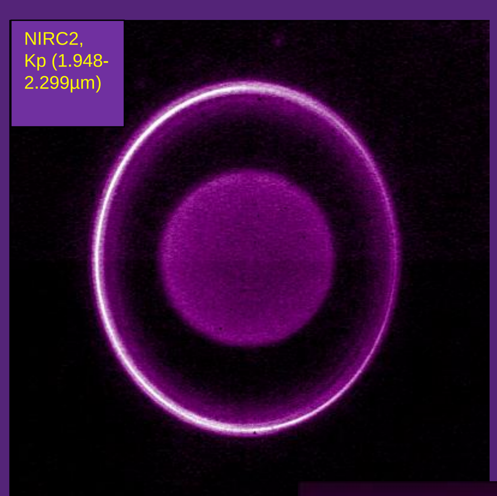
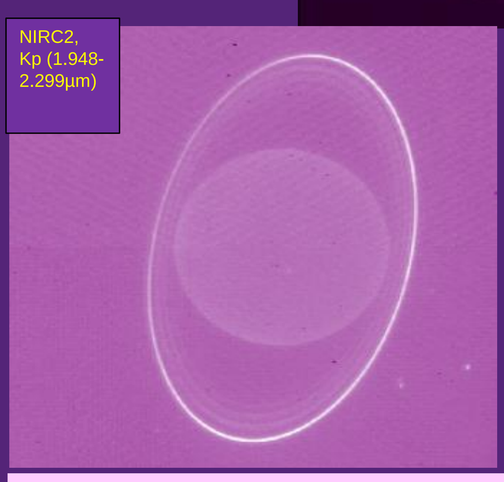
ABSTRACT

- So far, my work addresses a generic way to input an Image taken from the Keck observatory in Hawaii and output a radial and azimuthal profile. It can also output a close model to the radial profile of the rings. This model can output the relative brightness of the rings
- The model is generated by convolving the PSF (point-spread function; a property of telescope) with 9 Dirac-Delta functions, each represents a ring (perfect resolution model)! For the sake of a finer fit, I have added 3 extra degrees of freedom to the model, to account for the eccentricity of Alpha, Beta, and Epsilon ring.
- The very final goal of this research is to understand the surface roughness of the rings better by measuring their change in brightness as a function of phase angle.
- Note that we can literally input the below images into our developed programs and get , as output, the Models, and rings profiles.
- Enjoy these images taken from the planet Uranus and its rings!





- Next/ Future Steps: I am currently working toward extracting the full I/F for the rings. For the Epsilon ring the process is much more complicated since it does not have a uniform brightness, Hence we must use an azimuthal ring profile for this ring. I am also developing a much more scientifically efficient method for data masking as well.

What About Uranus?

- Yes! Uranus has rings! 13 of them!
- Uranus has 13 different distinct rings with different properties.
- Uranus has two sets of rings. The inner system of nine rings consists mostly of narrow, dark grey rings.
- The Epsilon ring is the most massive ring.
- The two outermost rings are faint, diffuse rings; the mu ring has a blue spectrum, while the nu ring has a red spectrum.
- In order of increasing distance from the planet, the rings are called Zeta, 6, 5, 4, Alpha, Beta, Eta, Gamma, Delta, Lambda, Epsilon, Nu, and Mu.

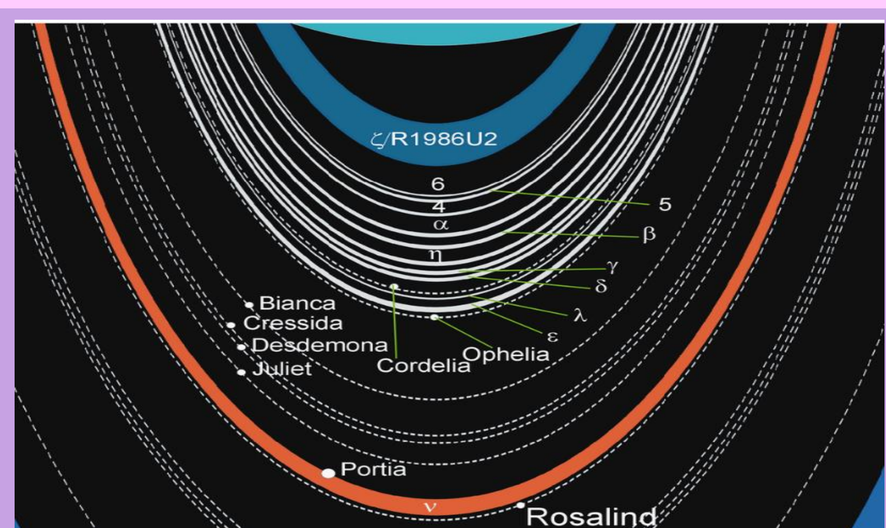


Fig.1- Uranian rings scheme

Why Uranus' Rings?

Studying the ring systems will eventually help us to understand many other interesting phenomena. We study these systems for three key reasons:

1) They provide a wealth of information about the history and ongoing evolution of the planetary systems of which they are a part
2) They are dynamical analogues for protoplanetary disks, exhibiting many of the same processes, but much easier for us to observe.
3) Their many mysterious and unexpected properties makes them worthy of study such as moon-ring 'shepherding' mechanism (Showalter 2020).

Uranus Missions Time-line

- 1977- Voyager 2 launched
- 1986- Voyager 2 reached Uranus! 10 years later!
- 2031-Next launch to Uranus by: "Uranus Orbiter and Probe" is planned
- 2044-will have our second orbiter reach the Uranus! After 60 years!

Algorithm? APERTURE PHOTOMETERY!

- The general method in acquiring these information is Aperture Photometry.
- we start with the smallest possible annulus centered at the center of planet on the image, with the same opening and rotation angle.
- Then increase the radius of annulus gradually to get the largest possible annulus in the image (see fig.2).
- This yields a radial profile, which is the plot of flux vs distance from the center of planet in kilo-meters or pixels. Please see below! (fig.4, the OG data)

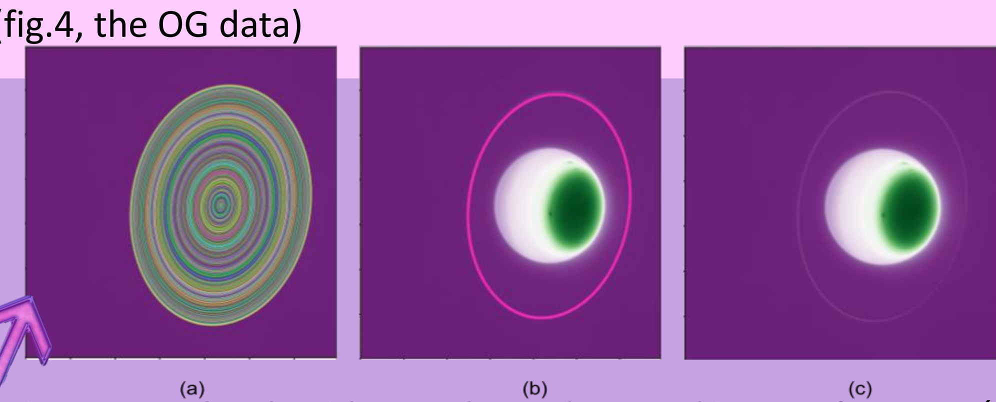


Fig.2 - How The algorithm works on the actual image of Uranus: (a): Creating all the possible specified annuli (b): the specific annulus of interest which in this case is the Epsilon ring (c): The original data

Detailed Procedures! How to Approach?

- Once we generate the radial profile of the rings, now our goal is to fit a curve. On this to measure the rings' brightness (for now).
- We modeled the light scattered by the planet as the leg of a Gaussian, and then subtract it from the H-band data. This step was not needed for K-band
- We create 9 Dirac-Delta functions (perfect resolution model) representing our 9 rings at the corresponding distance from the center of the planet
- We generate a PSF (point-spread function) from the outer edge of the Epsilon ring and then mirror it to the left to generate the left side.
- We use a boxcar averaging with a kernel width of 80 to smooth the wings of the PSF, and not the peak, to preserve the sharpness of the peak.
- Then we fit a 4th-degree polynomial (with 4 degrees of freedom) to make the PSF smoother.
- With these last 3 steps done, the PSF is completed, then we convolve the PSF with our perfect resolution model.
- Then we fit the model with the 9 degrees of freedom being the 9 amplitudes of Dirac-Delta functions. For a better fit we included 3 more degrees of freedom into our model to account for the eccentricity of the alpha, beta and epsilon rings. You can see the fit and the original data with a plot of residuals on (fig.4)
- Finally, the model was applied to all the dates on both Northern and Southern ansae individually, This table is important, since it includes all the relative fluxes for the rings, and it will lead to one our final tables (fig.7).

Planet Masking: A Way to Survive!

- The light scattered off the planet interferes with the ring 's flux hence limiting our ability to analyze the rings.
- By masking out a very large portion of the planet (the effected portion) we can increase the accuracy of our results significantly.
- look at the two Figueres below and reflect on how masking increases the quality and details in the plots! (fig.3)

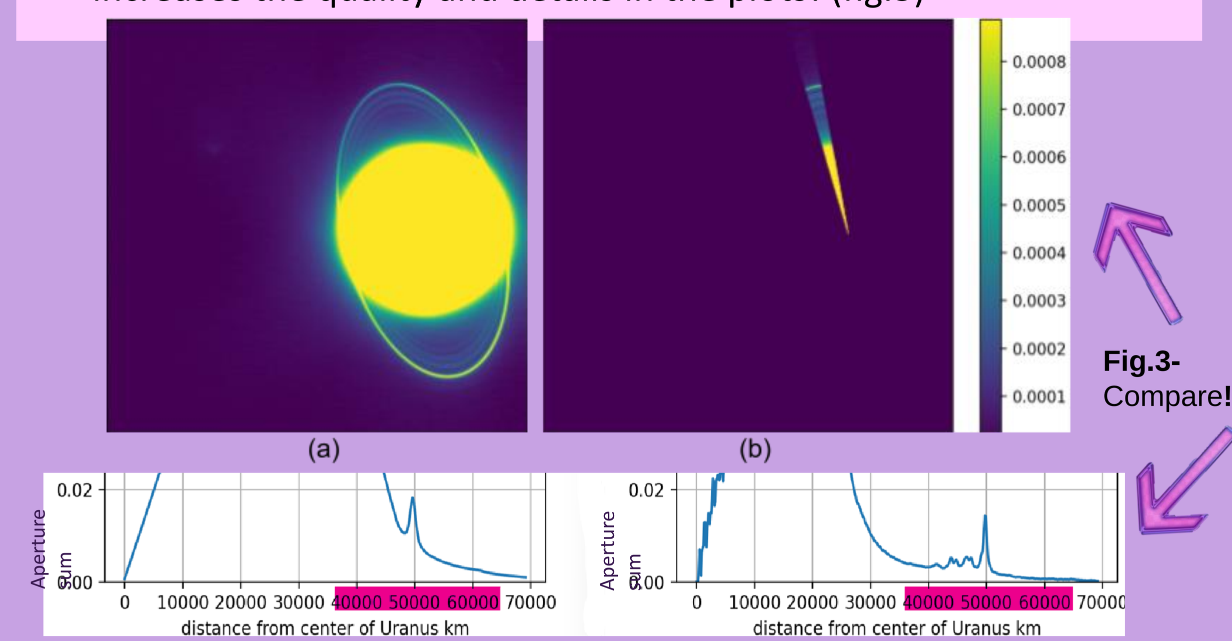


Fig.3- Compare!

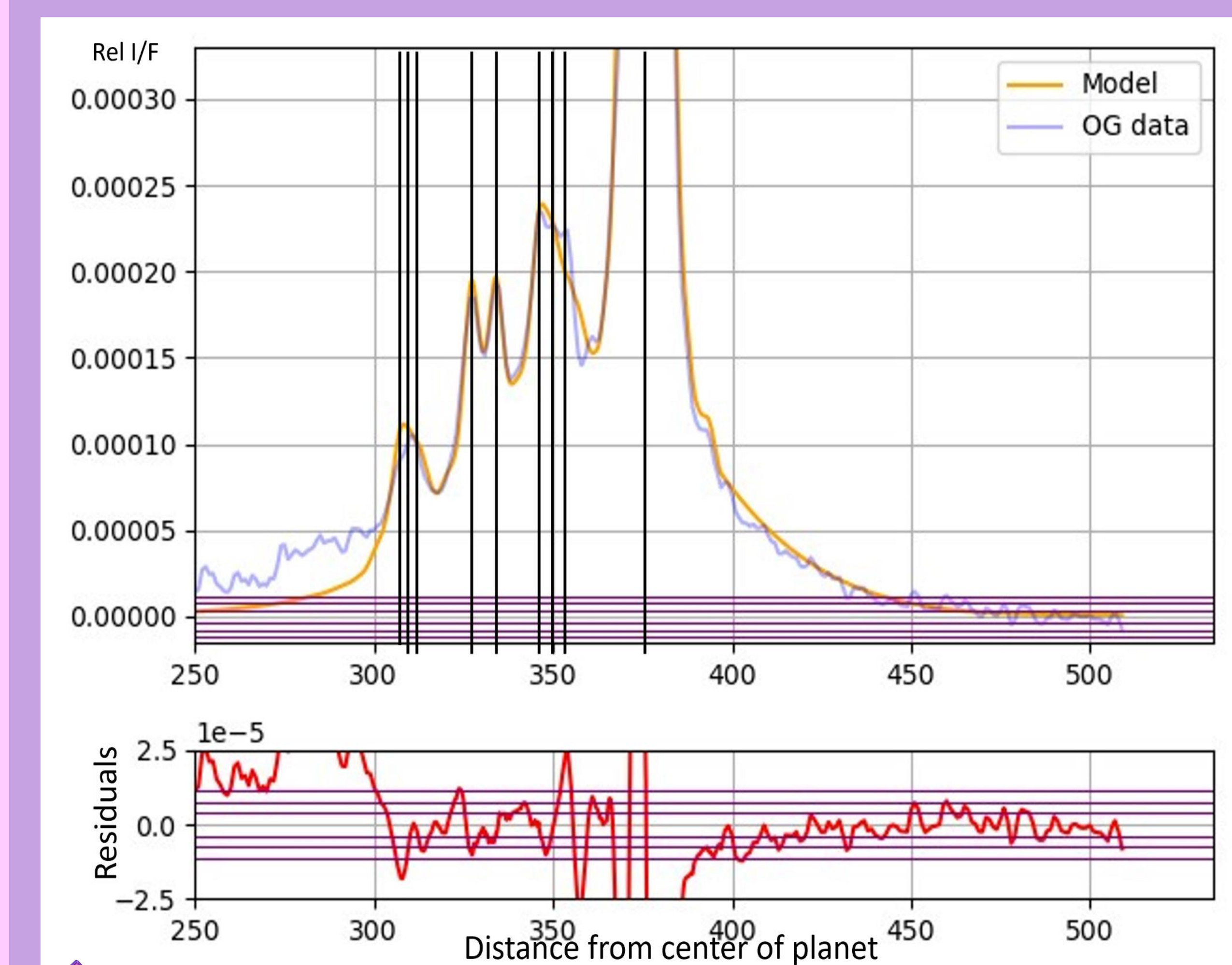
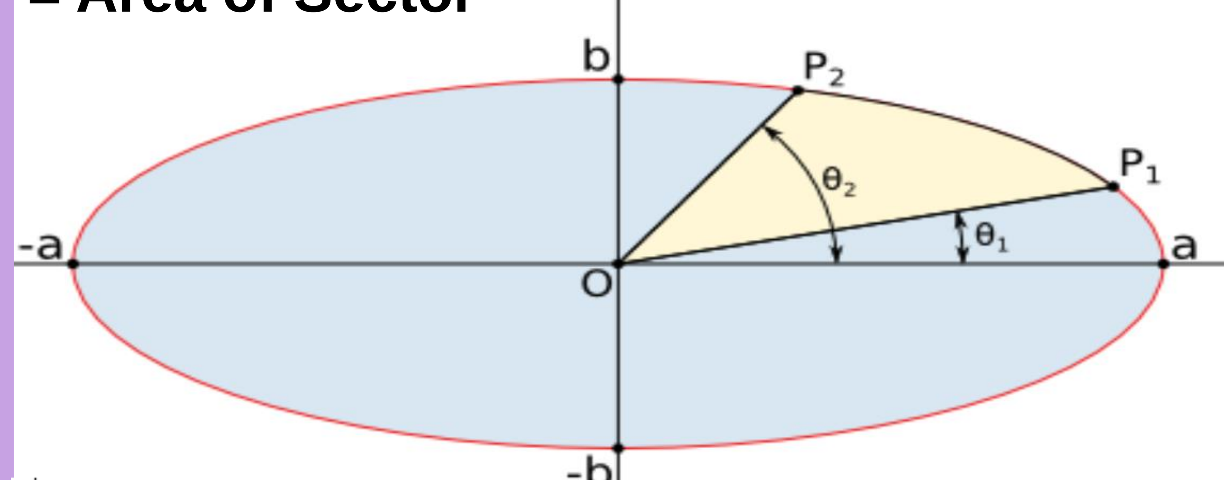


Fig.4- Comparison of the model vs our fit. You can see the 9 Dirac-Delta functions. On the bottom you can see a plot of the residuals as well. The model seems reasonable

Sector Area of Elliptical Annulus!

$$\frac{1}{2}ab\left(\tan^{-1}\left(\frac{a\tan(\theta_2)}{b}\right)-\tan^{-1}\left(\frac{a\tan(\theta_1)}{b}\right)\right)$$

= Area of Sector



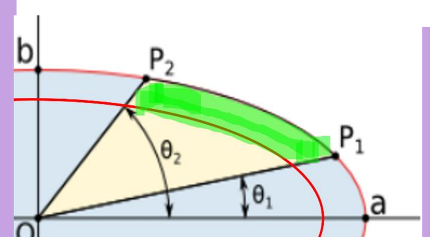


Fig.5- Equation for sector area of an ellipse. From this it is easy to see the sector area of an elliptical annulus (in green).

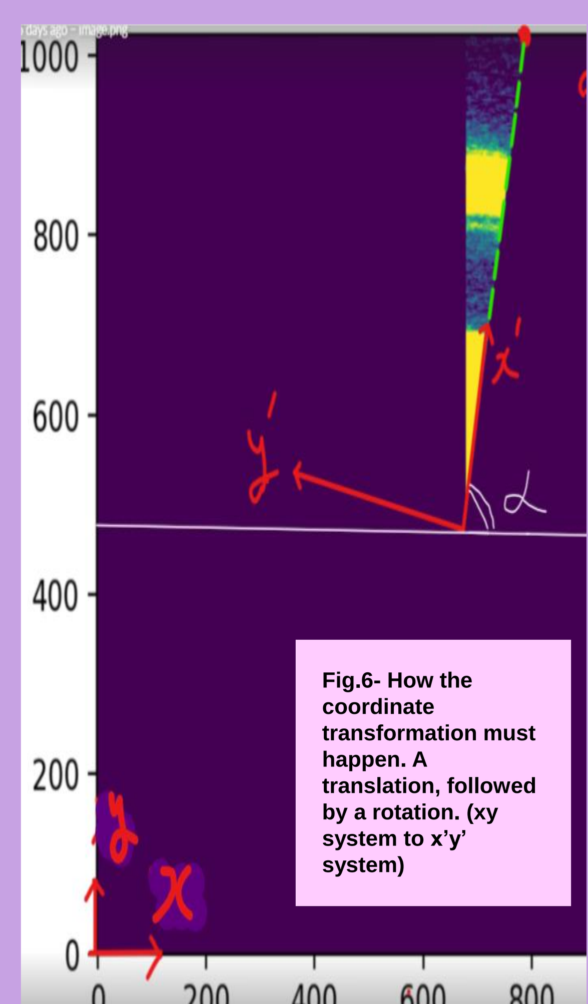


Fig.6- How the coordinate transformation must happen. A translation, followed by a rotation. (xy system to x'y' system)

- In our unit conversions, we encountered a problem: Finding the ***sector area of an elliptical annulus***. The formula of the sector area of the ellipse is provided on (fig.5) as well as an outline of the sector area of an elliptical annulus.
- In order to find this area a coordinate transformation must happen in two steps (fig.6):

1. The origins are translated from (0,0) to the center of the planet, aligning the coordinate system with a new reference point.
2. The system is rotated by an angle corresponding to the rotation of the Epsilon ring, accessible from previous radial profile codes.

==================== K-Band ====================

File	eps	del	gam	eth	bet	alp	fou	fiv	six
koct2019N.npy	0.0018208	0.0000608	0.0000841	0.0001238	0.0001113	0.0001254	0.0000313	0.0000340	0.0000584
koct2019S.npy	0.0015635	0.0000725	0.0001185	0.0001438	0.0001205	0.0001671	0.0000216	0.0000214	0.0000902
knov2019N.npy	0.0019378	0.0000720	0.0001061	0.0001698	0.0001179	0.0001443	0.0000367	0.0000373	0.0000694
knov2019S.npy	0.0018696	0.0000989	0.0001458	0.0001553	0.0001162	0.0001791	0.0000381	0.0000482	0.0000850
kaug2015N.npy	0.0018694	0.0000662	0.0000873	0.0001358	0.0001340	0.0001364	0.0000382	0.0000363	0.0000695
kaug2015S.npy	0.0010755	0.0001647	0.0001253	0.0002559	0.0001952	0.0002559	0.0000622	0.0000013	0.0001325

Fig.7- Final table as of July 26th. You can read the relative values of I/F for each ring at each ansa (Northern, Southern) on different dates. Note that some more conversion is still needed in order to get the total ring fluxes.